4.0 DAM MAINTENANCE AND REPAIR

4.1 OVERVIEW

A good maintenance program can protect a dam against deterioration and prolong its life. A poorly maintained dam will deteriorate and may eventually lead to failure. Therefore, all dams should have an effective, well planned maintenance program. Nearly all the components of a dam and the materials used for dam construction are susceptible to damaging deterioration if not properly maintained. A good maintenance program provides protection for the owner and for the general public as well, especially property owners located downstream. The cost of a proper maintenance program is small compared to the cost of major repairs, loss of life and property, and resultant litigation.

Two different types of maintenance operations should be performed at all dams: (1) preventive maintenance, sometimes referred to as routine, or scheduled maintenance, and (2) repair maintenance, sometimes referred to as unscheduled maintenance. Preventive maintenance should be scheduled and performed at a regular frequency. It normally includes the same items each time, such as mowing grass and removing brush, repair of minor erosion rills, removal of burrowing animals, reseeding bare areas, riprap replacement, lubrication and/or painting of mechanical devices, etc. The dam O&M plan should itemize all routine maintenance items, including a description of the work, a schedule, and the resources required to perform the work. Repair maintenance is the work required to correct deficiencies that are discovered during inspections or emergencies. This type of maintenance can not be scheduled until it is observed, and may be unpredictable. Repair maintenance may include such things as repair of embankment slides, removal of large trees from the embankment, replacing a trash rack, repairing significant embankment settlement or erosion, etc.

Dam owners should develop a schedule for preventive maintenance and incorporate it into the O&M plan for the facility. In general, it is recommended that the entire program of preventive maintenance be performed at least twice per year. Preferably, preventive maintenance should be performed once in the spring, soon after winter snowmelt, and once in the late fall, sometime before the first snowfall. In addition, each dam owner should assess whether his facility has areas or items which require maintenance on a more frequent basis (i.e., daily, weekly, or monthly). For example, mowing may need to be performed more frequently.

Repair maintenance needs to be prioritized so that it is completed in a timely manner. Repair maintenance is a task which should never be neglected. If it is, the damage could get worse, requiring more extensive and more costly repairs.

Table 4-1 summarizes the various problems or conditions that might be encountered at a dam, categorized by relative priority. This table can be used by dam owners to help them prioritize their own maintenance repairs.

Table 4-1 Summary of Potential Maintenance by Priority

(1) Preventive maintenance (These tasks should be performed on a continuing basis)

- Routine mowing and general maintenance
- Maintenance and filling of cracks and joints on concrete dams
- Observation and monitoring of springs or areas of seepage
- Inspection of the dam (as discussed in Part 3)
- Monitoring of development in the watershed which would materially increase runoff from storms
- Monitoring of development downstream and updating the emergency notification plan to include new homes or other occupied structures within the area
- Monitoring and evaluation of instrumentation (if installed)

(2) Repair Maintenance (These tasks should be repaired as soon as possible, as indicated)

Immediate maintenance (The following conditions are critical and call for immediate attention)
- A dam about to be overtopped or being overtopped
- A dam about to be breached (by progressive erosion, slope failure, or other circumstances)
- A dam showing signs of piping or internal erosion indicated by increasingly cloudy seepage or other symptoms
- A spillway being blocked or otherwise rendered inoperable, or having normal discharge restricted
- Evidence of excessive seepage appearing anywhere at the dam site (an embankment becoming saturated, seepage exiting on the downstream face of a dam) increasing in volume.

Although the remedy for some critical problems may be obvious (such as clearing a blocked spillway), the problems listed above generally require the services of a Professional Engineer familiar with the construction and maintenance of dams. The emergency action plan (EAP) should be activated when any of the above conditions are noted.

Required maintenance at earliest possible date - The following maintenance should be completed as soon as possible after the defective condition is noted:
- All underbrush and trees should be removed from the dam, and a good grass cover should be established
- Eroded areas and gullies on embankment dams should be restored and reseeded as soon as weather permits
- Defective spillways, gates, valves, and other appurtenant features of a dam should be repaired
- Deteriorated concrete or metal components of a dam should be repaired as soon as weather permits

This chapter is intended to provide a guide and reference to all individuals performing dam maintenance. Each subchapter covers a specific type of maintenance (e.g, vegetation, erosion, seepage), and includes both preventive and repair maintenance. Complex repair work may require additional reference or expertise, and may require the help of a qualified dam safety professional. The dam owner or inspector should use the results of inspections to help identify any dam maintenance and repair work that may be required. Quick corrective action to conditions requiring attention will promote the safety and extend the useful life of the dam while possibly preventing costly future repairs.

If dam repairs involve significant modifications, such as replacing the spillway structures or altering the embankment, IDNR approval may be required. It is a good idea to consult with IDNR Division of Water personnel before any major work is performed on dams that are under IDNR jurisdiction.

Every dam owner should develop a basic maintenance program based on systematic and frequent inspections. As noted in Part 3, inspections should be performed on a regular basis, and after major flood or earthquake events. Dam inspectors and operating personnel should prepare a list of items requiring maintenance or repair along with recommendations, priorities, and schedules every time a dam is inspected.

4.2 VEGETATION

4.2.1 Grass

The establishment and control of proper vegetation is an important part of dam maintenance, and is required under Indiana Code 14-27-7.5. Properly maintained vegetation can help prevent erosion of the embankment and earth channel surfaces, and aid in the control of groundhogs and muskrats. The uncontrolled growth of vegetation, or inappropriate vegetation, can damage embankments and concrete structures and make close inspection difficult.

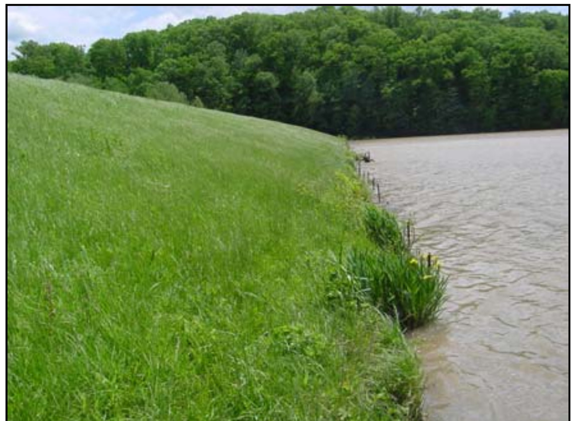

Figure 4-1 Embankment with excellent grass cover on upstream slope.

Grass vegetation is an effective and inexpensive way to prevent erosion of embankment surfaces. Grass is the only vegetation that is recommended for use on dam embankments. If properly maintained, it also enhances the appearance of the dam and provides a surface that can be easily inspected. Roots and stems tend to trap fine sand and soil particles, forming an erosion resistant layer once the plants are well established. Grass vegetation is least effective in areas of concentrated runoff, such as the contact of the embankment and abutments, or in areas subjected to wave action. Types of grass vegetation that have been used on dams in Indiana are fescue, rye grass, bluegrass, Bermuda grass, brome and reed canary grass. Sericea Lespedeza and crown vetch are not recommended in the spillway or on the dam embankment. IDNR permission may be required to use tall fescue.

Establishing vegetation on a dam depends on where the dam is located, the type of soil, the steepness of slope, and the orientation of the embankment. The vegetation proposed for the groin area and emergency spillway areas where there is flowing water might be different than the vegetation proposed for the steep slopes of the embankment. Owners may wish to contact the local field office of the Natural Resource Conservation Service (formerly Soil Conservation Service) or the local county extension office for recommendations on the establishment of this vegetation.

Maintaining a good, thick grass cover on an embankment dam at an appropriate height is one aspect of maintaining and keeping a dam safe. A dam is like any other man-made structure that creates a hazard; it needs to be maintained for safety and proper performance.

The purpose of keeping a healthy stand of grass at an appropriate height year round on the embankment and spillway is to: 1) protect the surface from extreme runoff events; 2) create a continuous, stable, near surface soil layer; 3) minimize woody/animal penetrations; 4) allow visual monitoring for early detection of safety deficiencies (seepage, wet spots, cracks, settlement, bulges, misalignment, sloughs, rills, holes, etc.) by the owner; and 5) prevent deterioration of the deeper compacted soils of the embankment.

A uniform, vigorous, turf forming grass stand that can tolerate stressful conditions (drought to very wet), survive high flows from runoff, provide protection to the underlying soil and allows for visual inspection of the structure is acceptable. A turf-type tall fescue would be an acceptable seed to use. Other grasses included in the mixture should be suitable for erosion control and steep slopes.

Grasses that are substantially clumpy, extremely deep-rooted, matt, spread or intertwine on the surface are not acceptable. Extremely deep-rooted grasses may compromise the integrity of the compacted embankment fill. A dense matted grass that creates a tangled mass will hide surface deficiencies and cause difficulty for the owner to routinely inspect and monitor the structure.

Crown vetch (Coronilla varia), a perennial plant with small bi-colored (pink and white) flowers is not recommended on dams. Crown vetch obscures the embankment surface, preventing early detection of cracks, erosion, and other damage. Large weeds, brush and trees can become established and periodic hand labor is then required to remove unwanted tall vegetation. Crown vetch is not effective in preventing erosion in some areas and is also expensive to establish.

Sericea Lespedeza (Lespedeza cuneata), an upright perennial summer legume is not recommended for use on dams or spillways. Sericea Lespedeza grows to a height of 3 to 5 feet. It grows in clumps, attracts burrowing animals, and obscures the surface of the dam. Sericea Lespedeza is not effective in preventing surface erosion.

Before seeding unvegetated areas, fertilizer and lime should be applied. Exact quantities necessary will vary with soil type and condition, and can be determined by having the soil tested. The fertilizer and lime should be raked, disked, or harrowed into the soil to a depth of not less than 4 inches. Periodic fertilization may be necessary to maintain vigorous vegetation.

The seed should be thoroughly mixed and evenly sown. The rate of seeding depends on the type of seed, percent purity, percent germination, and whether or not it is being incorporated into a seedbed, or applied as a dominant seeding on top of the ground. The seed should be covered with soil to a depth of approximately 1/4 inch, or rolled sufficiently. Immediately following planting, the area should be mulched with hay or straw at a rate of 2 to 3 tons per acre. Mulching materials should be kept in place with a mulch anchoring device or with asphalt emulsion. Steep slope areas may require the use of temporary or permanent erosion control fabric.

Weeds can prevent the growth of desirable grasses and should be eliminated or avoided. Once weeds become established, they are difficult to remove or control.

Establishing a good growth of grass will help prevent the growth of weeds.

Proper, routine maintenance is essential to keep the "design/spec" grass cover in a healthy condition to obtain the expected performance. Poor care and maintenance allow undesirable grasses, weeds and woody growth to overcome the acceptable grass.

Establishment and maintenance of the grass is fully as important as the engineering design of the dam. To develop good grass cover requires proper establishment and maintenance techniques such as fertilizer applications, mowing, spraying, cutting of brush and reseeding bare spots.

4.2.2 Trees and Brush

Trees and brush should not be permitted on embankment surfaces or in vegetated earth spillways. Extensive root systems can provide seepage paths for water. Trees that blow down or fall over can leave large holes in the embankment surface that will weaken the embankment and can lead to increased erosion or dam breaching. Trees and brush obscure the surface limiting visual inspection, provides a haven for burrowing animals, and retards growth of grass vegetation. Tree and brush growth adjacent to concrete walls and structures may eventually cause damage and should be removed. Some root systems can decay and rot, providing passageways for water, and thus cause erosion. Growing root systems can lift concrete slabs or structures, and can penetrate and damage drain systems. Trees and brush that are within 25 feet of the dam should be removed.

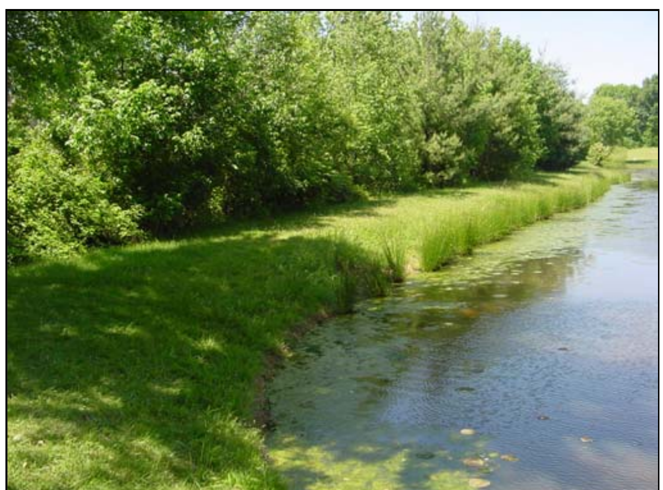

Figure 4-2 Embankment dam with excessive vegetation (trees) on downstream slope

Most tree roots are located in the top 6 to 24 inches of the soil and occupy an area of two to four times the diameter of the tree crown. The roots are located in this soil horizon because that’s where most of the water, oxygen, and soil nutrients can be found. The roots obtain water, oxygen, and minerals from the soil; they do not grow “toward” anything or in any particular direction. Root systems consist of large perennial roots and smaller, short-lived, feeder roots. The large woody tree roots and their primary branches increase in size and grow horizontally. They are predominately located in the top 6 to 24 inches of the soil and usually do not grow deeper than 3 to 7 feet. Functions of the large roots include water and mineral conduction, food and water storage, and anchorage. These are the roots that can cause seepage problems in the dam embankments. Feeder roots average about 1/16 inches in diameter and constitute the major portion of the root system's surface area. These smaller roots grow outward and predominately upward from the large roots near the soil surface, where minerals, water, and oxygen are relatively abundant. The major function of the feeder roots is the absorption of water, oxygen, and minerals. Under normal conditions, these roots die and are replaced on a regular basis. Sometimes trees will develop tap roots, however, they usually do not. Oak trees, walnut, and ash trees will frequently grow a tap root, whereas maples, ash, fir, birch, and cottonwood trees often do not. Tap roots will only grow where soil conditions are favorable, depending on moisture, oxygen supply, soil texture, obstacles, other roots, and animals. Root systems are modified by their environment; more roots will grow in more favorable the soil conditions. Tap roots are rarely found in areas where the sub-soils are very dense or heavily compacted.

The following guidelines should be used when removing trees from dams:

Small trees (less than 6 to 12 inches)

- cut flush, remove all trunk and branches from site
- treat stump if possible to prevent regrowth

Large trees (greater than 6 to 12 inches)

- lower water level in reservoir to safe level
- remove tree, stump, rootball, and perennial roots (depending on location)

upstream slopes
- remove rootball
- excavate a bench where rootball was extracted
- backfill bench with compacted, cohesive soil
- install wave erosion protection

crest
- remove rootball and major roots
- clean rootball cavity
- backfill rootball cavity with compacted, cohesive soil
- plant grass

steep downstream slopes (> 2.5H:1V)
- cut trees with 2 to 3-ft stumps
- extract stumps with rootball
- remove roots during benching
- flatten slopes with compacted, cohesive soil
- install embankment toe drain system

moderate to flat downstream slopes (< 2.5H:1V)
- upper 1/3 of slope height
  - ► use same procedure as crest of dam
- middle 1/3 of slope height
  - ► remove rootball and major roots
  - ► clean rootball cavity
  - ► backfill rootball cavity with compacted, cohesive soil, or

install a filtered drain system
- ► plant grass where necessary
- ● lower 1/3 of slope height
  - ► use same procedure as steep downstream slopes

beyond toe of downstream slopes

- ● remove rootball and major roots
- ● clean rootball cavity
- ● install a filtered drain system or weighted filter system
- ● plant grass where necessary

Rodent habitats can develop when brush is cut down, so the cuttings should be removed from a dam to permit a clear view of the embankment. Following removal of large brush or trees, the left over root systems should also be removed if possible and the resulting holes properly filled. In cases where they cannot be removed, root systems can be treated with herbicide (properly applied) to retard further growth. After the removal of brush, cuttings may need to be burned. If this is done, dam owners should notify the local fire department, forest service, or other agency responsible for fire control.

4.2.3 Maintenance of Vegetation

Embankments, areas adjacent to spillway structures, vegetated channels, and other areas associated with a dam require continual maintenance of the vegetative cover. Grass mowing, brush cutting, and removal of woody vegetation (including trees as described above) are necessary for the proper maintenance of a dam. All embankment slopes and vegetated earth spillways should be mowed at least twice a year. Mowing promotes the formation of a sod, prevents trees and brush from growing, and gives a neat well kept appearance to the dam. Aesthetics, unobstructed viewing during inspections, maintenance of a non-erodible surface, and discouragement of groundhog habitation are reasons for proper maintenance of the vegetal cover.

Many methods are available for vegetation control. Acceptable methods include the use of weed whips or power brush-cutters and mowers. Chemical spraying to first kill small trees and brush is acceptable if precautions are taken to protect the local environment. Manufacturer's recommendations should be followed when using chemical herbicides.

A wide variety of tools, attachments, and power equipment is available for satisfactory maintenance of vegetation. Hand-held brush cutters or weed whips range in weight from about 13 to 28 pounds. Cutting widths range up to about 21 inches, and there are various cutting blades including nylon string, plastic blades, and metal knife blades. These units can be used to cut grass, brush, woody vegetation up to 4 inches in diameter and can be used on almost any slope. Hand mowers are available in both push and self-propelled models. Width of cut varies up to a maximum of about 36 inches while maximum cutting height is about 4 inches. Hand mowers can be used safely on many slopes.

Garden and lawn tractors are available from 10 horsepower to a maximum of about 20 horsepower. They can be provided with wheels of different widths and with turf or agricultural tires. These type tractors may be equipped with four-wheel drive. Self-leveling units are also available for use on slopes. Power take-off drives are available for attachment to mowers and other accessories. Tractor speeds range to a maximum of about 7 miles per hour. Mower units are normally rotary, but pull-type flail and reel-type units are also available. Cutting height is a maximum of 7 inches and width of cut is from 36 to 60 inches. A garden tractor equipped with a 48-inch mower can mow about 1 acre an hour, depending on the slope and thickness of vegetation.

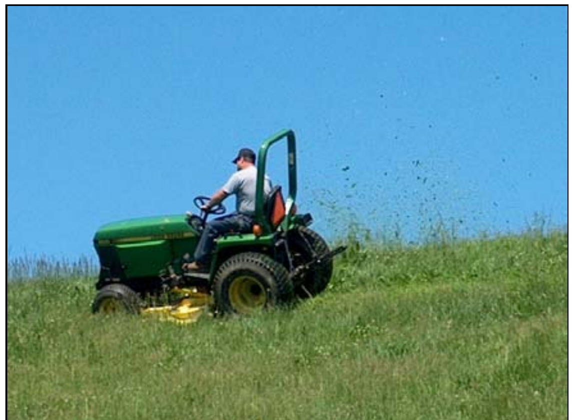

Figure 4-3 A lawn tractor being used to cut grass on an embankment dam.

Large farm tractors are available in engine sizes ranging from 22 horsepower up to 50 horsepower and higher. They are available in low profile models with four-wheel drives, self-leveling units for use on slopes, adjustable front and rear wheel widths, agricultural or turf tires, and power take-off drives for various accessory units. Maximum speeds are around 12 miles per hour. Mowing units, including rotary, reel, flail, and sickle bar types, are available for the large tractors. The tractor horsepower should be matched to the mowing unit needed for the job per the manufacturer's recommendations. The garden and farm tractors described in this manual cannot be used safely on slopes steeper than 2.5H:1V (40% or 21.80-degree slope). The larger tractors should be obtained with the lowest profile (or center of gravity) necessary for the type of slope to be mowed. Dual wheels or wider tires can be used to increase stability. All of these units should be equipped with safety roll bars designed to support the full weight of the tractor.

Self-contained mowing units are also available with self-leveling suspension for mowing very steep slopes. It is important to remember to use the proper equipment for the slope and type of vegetation to be cut, to always follow the manufacturer's recommended safe operation procedures, and not to mow when the vegetation is wet. Mowing should be done horizontally to prevent the formation of ruts aligned with the slope. Ruts can channel runoff and form erosion gullies.

Livestock should not be allowed to graze on the grass on the embankment surface. When the soil is wet, livestock can damage the vegetation and destroy the smooth surface resulting in ponded water or erosion from concentrated runoff. The resulting rough surface is difficult to mow. Cattle also tend to walk in paths killing the vegetation and forming channels for runoff. Livestock paths should be graded, seeded, and mulched. Livestock should be fenced off the dam and spillways.

No vehicles, other than maintenance vehicles, should be allowed on embankments. Maintenance vehicles should be kept off the embankment when it is wet to minimize rutting and damage to the vegetation.

Listed below are some considerations in maintaining the grass cover on the dam and spillway. There may be other site-specific factors that need to be considered.

- Grass on significant or high hazard dams or on dams that are a valuable resource should be mowed not burned. Burning a dam leaves the surface of the ground exposed to erosion for an extended period of time. Further, burning may overstress the design/spec grass and allow undesirable vegetation to establish.
- Mowing frequency will depend on what the turf can stand. Mowing just after seed has formed but before maturity will slow the growth of the turf for the rest of the summer. This would allow for good inspection and not cause as frequent of mowing.
- Mowing to six (6) inches is acceptable if the above item is followed. Mowing off no more than 1/3 of the leaf blade is standard for good turf management. By mowing off more, the turf is stressed and its growth slowed. Care must be taken not to stress the turf unduly by improper maintenance.
- Proper mowing equipment should be used to minimize rutting the slope, reduce damage to the grass, and provide safety for the operator.
- Slope trash (logs, stones, etc.) should be removed and ruts filled with compacted (similar) soil material to provide a uniform cut an4 minimize equipment damage and injury to the operator.
- Thick grass clippings or large clumps should be removed to keep the underlying grass from dying.
- After each mowing, the dam owner should thoroughly inspect the dam for deficiencies. If there are new deficiencies or significant changes in previous deficiencies, the dam owner's engineer and the Division of Water should be contacted.
- Bare spots should be seeded and fertilized. Weeds and woody growth should not be allowed to establish.

4.3 EROSION

Erosion of slopes, abutments, and spillway discharge channels is one of the most common maintenance problems with embankment structures. Erosion is a natural process, and its continuous forces will eventually wear down almost any surface or structure. Erosion can be caused or aggravated by improper drainage, settlement, pedestrian traffic, inadequate vegetation, animal burrows, or other factors. The cause of the erosion will have a direct bearing on the type of repair needed. Erosion in and around dams can lead to failure of a dam if left untreated. Periodic and timely maintenance is essential in preventing continuous deterioration and possible failure.

A sturdy sod, free of weeds and brush, is one of the most effective means of erosion protection. Embankment slopes are normally designed and constructed so that the surface drainage will be spread out in thin layers as "sheet flow" on the grassy cover. When the sod is in poor condition or flows are concentrated at one or more locations, the resulting erosion will leave rills and gullies in the embankment slope. The owner or inspector should look for these areas and be aware of the problems that may develop.

Prompt repair of vegetated areas that develop erosion is required to prevent more serious damage to the embankment. Rills and gullies should be filled with suitable soil (the upper 4 inches should be topsoil, if available), compacted, and then seeded. Erosion in large gullies can be slowed by stacking bales of hay or straw across the gully until permanent repairs can be made.

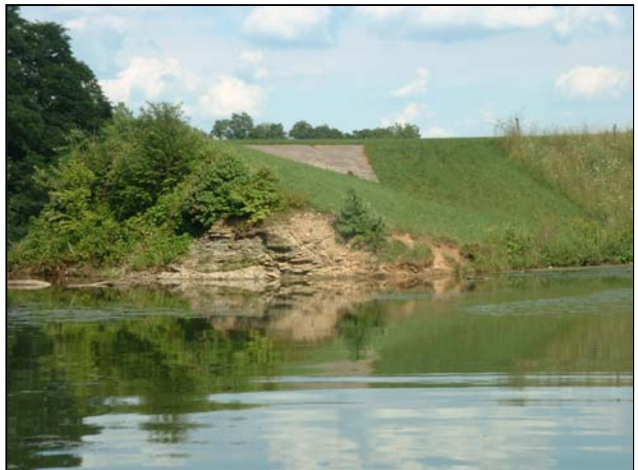
Figure 4-4 Erosion along the shoreline of an embankment dam.

Not only should the eroded areas be repaired, but the cause of the erosion should be addressed to prevent a continuing maintenance problem. Erosion might be aggravated by improper drainage, settlement, pedestrian traffic, animal burrows, or other forces. The cause of the erosion will have a direct bearing on the type of repair needed.

Paths from pedestrian and vehicle traffic are problems common to many embankments. If a path has become established, vegetation in this area will not provide adequate protection and more durable cover will be required, unless the traffic is eliminated. Small stones, asphalt, or concrete have been used effectively to cover footpaths. Embedding railroad ties or other treated wood beams into the upstream slope of the embankment to form steps is one of the most successful and inexpensive methods used to provide a protected pathway. Barriers should be constructed along paths used by motorcycles and off-road-vehicles to discourage their use on a dam.

Another area where erosion commonly occurs is the contact between the embankment and the concrete walls of the spillway or other structures. Poor compaction adjacent to the wall during construction and subsequent settlement could leave an area lower than the grade of the embankment. Runoff often concentrates along these structures, resulting in erosion. People frequently walk along these walls, wearing down the vegetal cover and compounding the problem. Possible solutions include grading the area to slope away from the wall and adding more resistant surface protection.

Adequate erosion protection is required along the contact between the downstream face of the embankment and the abutments. Runoff from rainfall concentrates in these gutter areas and can reach erosive velocities because of the steep slopes. Berms on the downstream face that collect surface water and empty into these gutters add to the runoff volume. Sod gutters may not adequately prevent erosion in these areas. Paved concrete gutters do not hold up well, will not slow the velocity of the water, can become undermined, and therefore are not recommended. Small animals often construct burrows underneath concrete gutters, possibly because burrowing is easier due to existing undermining. A well graded mixture of rock with stones 9 to 12 inches in diameter or larger placed on a sand filter generally provides the best protection in groins on small dams. Slush-grouted riprap (riprap filled with a thin concrete slurry) has also been successful in preventing erosion and can be used if large stone is not available or for groins of larger dams. A properly designed filter should be constructed beneath the slush grouted riprap.

As with erosion around spillways, erosion adjacent to gutters results from improper construction or a poor design in which the finished gutter is too high with respect to adjacent ground. This condition prevents much of the runoff water from entering the gutter. Instead, the flow concentrates along the side of the gutter, erodes and may eventually undermine the gutter. Care should be taken when replacing failed gutters or designing new gutters to assure that the channel has adequate capacity and erosion protection, a satisfactory filter, that surface runoff can easily enter the gutter, and that the outlet is adequately protected from erosion

A serious erosion problem which can develop on the upstream slope is "beaching." Waves caused by high winds or high-speed power boats can erode the exposed face of the embankment. Waves repeatedly strike the surface just above the pool elevation, rush up the slope, then tumble downward into the pool. This action erodes material from the face of the embankment and displaces it farther down the slope, creating a "beach". Erosion of unprotected soil can be rapid and during a severe storm could lead to complete failure of a dam. The upstream face of a dam is commonly protected against wave erosion and the resultant beaching by placement of a layer of rock riprap over a layer of filter material. In some cases other materials such as steel, bituminous or concrete facing, bricks or concrete blocks are used. Generally, rock riprap provides the most economical protection.

Beaching can also occur in existing riprap if the embankment surface is not properly protected by a filter. Water running down the slope under the riprap can erode the embankment. Sections of riprap slumped downward are often signs of beaching. Concrete facing used to protect slopes often fails because the wave action washes soil particles from beneath the slabs through joints and cracks. Detection, in this case, is difficult because the voids are hidden and failure may be sudden and extensive. Effective slope protection must prevent soil particles from being removed from the embankment.

When erosion occurs and beaching develops on the upstream slope of a dam, repairs should be made as soon as possible. The pool level should be lowered and the surface of the dam prepared for replacing the slope protection. A small berm or bench should be made across the face of the dam to help hold the protective layer in place. The bench should be placed at the base of the new layer of protection. The depth of the bench will depend on the thickness of the protection layer. The layer should extend a minimum of 3 feet below the lowest anticipated pool level. Otherwise, wave action during periods when the lake level is drawn down can undermine and destroy the protective layer. If rock riprap is used, it should consist of a heterogeneous mixture of irregular shapes placed over a sand and gravel filter. The maximum rock size and weight must be large enough to break up the energy of the maximum anticipated wave action and hold the small stones in place. Generally, the largest stones should be at least 12-24 inches in diameter. The smaller rocks help to fill the spaces between the larger pieces forming a resistant mass. The filter prevents soil particles on the embankment surface from being washed out through the spaces (or voids) between the rocks in the riprap. If the filter material can be washed out through these voids and beaching develops, two filter layers will be required. The lower layer should be composed of sand or filter fabric to protect the soil surface. The upper layer should be composed of coarser materials that prevent washout through the voids in the riprap.

The soil selected for repairing erosion should be free from vegetation, organic materials, trash, or large rock. Most of the soil should be fine-grained, cohesive soils which easily break down when worked with compaction equipment. The intent is to use a material which, when compacted, forms a firm, solid mass, free from excessive voids. The upper 4 to 6 inches should be topsoil capable of supporting vegetative growth.

If flow-resistant portions of an embankment are being repaired, materials which are high in clay or silt content should be used. If the area is to be free draining or highly permeable (i.e., riprap bedding, etc.) the material should have a higher percentage of sand and gravel. As a general rule, it is usually satisfactory to replace or repair damaged areas with soils similar to those originally in place.

An important soil property affecting compaction is moisture content. Soils which are too dry or too wet do not compact well. One may roughly test repair material by squeezing it into a tight ball. If the sample maintains its shape without cracking and falling apart (which means it is too dry), and without depositing excess water onto the hand (which means it is too wet), the moisture content is probably near the proper level.

Before placement of soil, the repair area must be prepared by removing all inappropriate material. Vegetation such as brush, roots, and tree stumps must be cleared and any large rocks or trash removed. Also, unsuitable earth, such as organic or loose soils, should be removed, so that the work surface consists of exposed firm clean embankment material. Following clean-up, the affected area should be shaped and dressed, so that the new fill can be compacted and will properly tie into the existing fill. If possible, slopes should be trimmed, and surfaces roughened by scarifying or plowing to improve the bond between the new and existing fill and to provide a good base to compact against.

Soils should be placed in loose layers up to 12 inches thick and compacted manually or mechanically to form a dense mass free from large rock or organic material. Compacted soil layers should not exceed 6 to 9 inches. Soil moisture must be maintained in the proper range. The fill should be watered and mixed to the proper wetness or scarified and allowed to dry if too wet. During backfilling, care should be taken so that the fill soil does not become too wet from rainstorm runoff. Runoff should be directed away from the work area and repair areas should be overfilled so that the fill maintains a crown which will shed water.

Preventive maintenance to help prevent erosion includes the following:

- Periodic mowing to prevent trees, brush, and weeds from becoming established, and to encourage the growth of grass. Poor vegetative cover will usually result in extensive and rapid erosion.
- Timely repair of erosion damage, particularly after high flows. Erosion can be expected in spillway channels during high flows and can also occur as a result of rainfall and local runoff. Local runoff is more significant in large spillways and may require special treatment, such as terraces or drainage channels. Erosion of the channel slopes deposits material in the spillway channel, especially where the slopes meet the channel bottom. In small spillways, this can significantly reduce the spillway capacity. This condition often occurs immediately after construction, before vegetation becomes established. In these cases, it may be necessary to reshape the channel to provide the necessary capacity.
- Seeding and fertilization as necessary to maintain a vigorous growth of vegetation. Fescue provides excellent erosion protection, but may require approval from IDNR before using it.
- Installation of erosion control fabrics.
- Use of straw/hay bales, or rock checks in swales where water concentrates.
- Post signage to prohibit pedestrian and vehicular access to sensitive areas.
- Prohibit fishing from the embankment.

4.4 SEEPAGE

All dams, regardless of type, have seepage in one form or another. Seepage may be through the foundation, through the embankment, or along the foundation-embankment interface. The seepage volumes may be substantial or barely noticeable. The water may be transporting suspended or dissolved solids. In some cases, the seepage may be entirely harmless; in others, it may be extremely serious and immediate treatment becomes imperative.

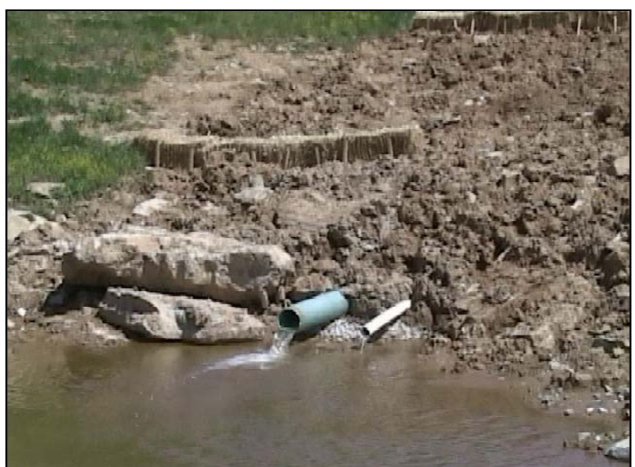

Figure 4-5 Seepage at this embankment dam is collected in a rock drain and discharged through a PVC pipe. This drain was recently installed as evidenced by the fresh soil fill.

Seepage can emerge anywhere on the downstream face of the dam, beyond the toe, or on the downstream abutments at elevations below normal pool. Seepage may vary in appearance from a "soft", wet area to a flowing channel of water. It may show up first as only an area where the vegetation is more lush and darker green. Cattails, reeds, mosses, and other marsh vegetation often become established in a seepage area. Downstream groin areas (the areas where the downstream face contacts the abutments) are prime areas for seepage. Seepage can also occur along the contact between the embankment and a conduit spillway, drain, or other appurtenance. Slides in the embankment or an abutment may be the result of seepage causing soil saturation or loss of soil strength. At most dams, some water will seep from the reservoir through the foundation. Where it is not intercepted by a subsurface drain, the seepage will emerge downstream from or at the toe of the embankment. If the seepage forces are large enough, soil will be eroded from the foundation and be deposited in the shape of a cone around the outlet. If these "boils" appear, professional advice should be sought immediately. Seepage flow which is muddy and carrying soil particles may be evidence of "piping," and complete failure could occur within hours. Piping can occur along a spillway and other conduits through the embankment, and these areas should be closely inspected. Sinkholes that develop on the embankment above buried conduits are signs that piping has begun and a professional engineer should immediately be retained to investigate the situation. If the extent of piping is large enough, rapid and complete failure of the dam could be imminent. Emergency procedures, including downstream evacuation, must be implemented if this condition is noted.

The need for seepage control will depend on the quantity, content, and location of the seepage. Other factors to be considered when evaluating seepage problems include the seepage path and pattern, configuration of the dam, and the engineering properties of the embankment materials. Controlling the quantity of seepage that occurs after construction is difficult, quite expensive, and not usually attempted unless drawdown of the pool level has occurred or the seepage is endangering the embankment or appurtenant structures. Typical methods used to control the quantity of seepage are grouting, installation of an upstream blanket, or slurry walls. Relief wells can be installed to relieve the water pressure in the foundation. Grouting is most applicable to leakage zones in bedrock, abutments, and foundations. Extreme care should be exercised when grouting in fill material. All these methods must be designed and constructed under the supervision of a professional engineer experienced with dams.

Controlling the content of the seepage or preventing seepage flow from removing soil particles is extremely important. Modern design practice incorporates this control into the embankment through the use of cutoffs, internal filters, and adequate drainage provisions. Control at points of seepage exit can be accomplished after construction by using weighted filters, drain pipes, trench drains, and other methods of drainage. The filter and drainage system should be designed to prevent migration of soil particles and still provide for passage of the seepage flow. Geotextiles or synthetic fabrics have worked quite well as filters in many applications; and should be considered by the engineer and the owner as a means of controlling seepage.

The bottom layer of the weighted filter should include 6 to 12 inches of sand placed over the seepage area. A properly designed geotextile should be placed beneath the sand or the gradation of the sand should be based on the particle sizes of the foundation or fill material. The sand layer should be covered with a gravel layer of similar thickness. Larger rock should be placed next, to complete the weighted filter (when placed above the ground surface, shape to form a berm). This method will permit the seepage to drain freely, but prevent piping (removal) of soil particles. The weight of the berm will hold the filter in place and may also provide additional stability to the embankment and foundation.

The location of the seepage or wet area on the embankment or abutment is often a primary concern. Excessive seepage pressure or soil saturation can threaten the stability of the downstream slope of the dam or the abutment slopes. An abutment slide might block or damage the spillway outlet or other appurtenances. In these cases, not only must the seepage be controlled but the area must be dried out. This is sometimes accomplished by installing finger drains (lateral trench drains for specific locations). Seepage control systems must always be free-draining to be effective.

Regular monitoring is essential to detect seepage and prevent failure. Without knowledge of the dam's history, the owner or the inspector has no idea whether the seepage condition is in a steady or changing state. It is important to keep written records of points of seepage exit, quantity and content of flow, size of wet area, and type of vegetation for later comparison. Photographs provide invaluable records of seepage. The inspector should always look for increases in flow and evidence of flow carrying soil particles. The control methods described previously are often designed to facilitate observation of flows. It is highly recommended that a v-notch weir be included in the design of a filter and drain system to measure the flow rates.

Regular surveillance and maintenance of internal embankment and foundation drainage outlets is also required. Normal maintenance consists of removing any soil or other material that obstructs flow. Internal repair is complicated and often impractical and should not be attempted without professional advice. The rate and content of flow emerging from these outlets should be monitored regularly.

4.5 EMBANKMENT STRUCTURE

The dam embankment and any appurtenant dikes must safely contain the reservoir. Cracks, slides, sloughing, and settlement are signs of embankment distress and indicate that maintenance or remedial work is required. The cause of the distress should be determined by a qualified dam safety professional before undertaking repairs on dams. This step is important because a so-called "home remedy" may cause greater and more serious damage to the embankment and may eventually result in unwise expenditures for useless repairs.

The entire embankment should be closely inspected for cracks. Short, isolated cracks are not usually significant, but larger (wider than 1 or 2 inches), well-defined cracks may indicate a more serious problem. There are three types of cracks: transverse, longitudinal, and diagonal. Transverse cracks appear across the embankment and indicate differential settlement within the embankment. Such cracks provide avenues for seepage water and piping could develop quickly. Longitudinal cracks run parallel to the embankment and may signal the early stages of a slide on either face of the embankment. In recently built structures, these cracks may indicate inadequate compaction of the embankment during construction. Diagonal cracks are intermediate vertical cracks that form in the embankment as a result of slides or differential settlement.

Small cracks, as they appear, should be documented, examined by an engineer, and then sealed. The seal will prevent surface water from entering the cracks, causing saturation of embankment material, and possibly triggering a slide or other serious problem. Sealing can be accomplished by compacting cohesive soil in the cracks. Unless the cracks are large (wider than an inch), this can usually be done in a few minutes using a shovel and a compacting tool. After the cracks have been sealed, the areas should be monitored frequently to determine if movement is still occurring.

Slides or crack locations should be documented by staking and photographs. Continued movement is an indication of a more serious problem such as a slide. Slides and sloughs are serious threats to the safety of a dam. A massive slide can initiate catastrophic failure of a dam. Slides can be detected easily unless obscured by tall vegetation. Arc-shaped cracks are indications that a slide or slough is beginning. These cracks soon develop into a large scarp in the slope at the top of the slide. If a slide develops, the scarp should be sealed to prevent rainfall and surface runoff from lubricating the interior slide surface, saturating the embankment, and causing future sliding. Sealing the scarp is only a temporary measure. The need for immediate professional assistance to determine the cause of cracks and slides and to recommend remedial action cannot be overemphasized.

Occasionally minor cracks will form in an earth dam because of surface drying. These are called desiccation (drying) cracks and should not be confused with structural or settlement cracks. Drying cracks are usually parallel to the main axis of the dam, typically near the upstream or downstream shoulders of the crest. These cracks often run intermittently along the length of the dam and may be up to 4 feet deep. Drying cracks can be distinguished from more serious structural cracks because the former are usually no wider than a few inches and have edges that are not offset vertically. As a precaution, suspected drying cracks should initially be monitored with the same care used for structural cracks. The problem area should be marked with survey stakes, and monitoring pins should be installed on either side of the crack to allow recording of any changes in width or vertical offset. Once satisfied that observed cracking is the result of shrinkage or drying, an owner may stop monitoring. These cracks will often close as climatic or soil moisture conditions change. If they do not, it may be necessary to backfill the cracks to prevent entry of surface moisture which could result in saturation of the dam. The cracks may be simply filled with cohesive soil that is tamped in place with hand tools. It is also recommended that the crest of a dam be graded to direct runoff waters away from areas damaged by drying cracks.

Slide debris in spillway and outlet areas should be removed immediately, because the debris reduces hydraulic capacities. Shallow surface slides can be repaired by removing the slide material and rebuilding the slope to original grade with well compacted impervious, cohesive soil material. The cause for any slide should be fully determined before implementing permanent repairs to the slope.

Settlement occurs both during construction and after the embankment has been completed and placed in service. To a certain degree, this is normal and should be expected. Settlement is usually most pronounced at locations of maximum foundation depth or embankment height. Excessive settlement will reduce the freeboard (the difference in elevation between the water surface and the top of the dam) and may increase the probability of overtopping. Any areas of excessive settlement should be restored to original elevations and conditions to reduce the risk of overtopping. A relatively large amount of settlement (more than one foot) within a small area could indicate serious problems in the foundation or perhaps in the lower part of the embankment. Settlement accompanied by cracking often precedes failure. When either condition is observed, professional advice should be sought. Settlement can be monitored by measuring the differences in elevation between the problem area and permanent reference monuments located away from the dam. Land surveying instruments are required to make these measurements.

Repair of cracks, slides, and settlement in dams usually requires the removal of all unsuitable material and the addition of good material to the embankment. Filters and drains may also be necessary to correct these problems. Soil added to restore an embankment should be properly "keyed" into the base material. This can best be accomplished by removing the vegetal cover and all unsuitable material until a good, firm base in undisturbed soil is uncovered. Unsuitable materials include wet, soft; porous, organic, and improperly compacted soils. The surface should then be roughened with a disc or similar device to obtain a good bond between "old" and "new" materials. The new soil should be successively compacted in thin layers (6 to 9 inches thick) before adding more material. Compaction of each layer to at least 95 percent maximum dry density at 1 percentage point below to 3 percentage points above optimum moisture content based on the Standard Proctor density test (ASTM D698) is recommended for cohesive soils used in dams.

Soils used for repair of embankment problems should be the same as that as described earlier in Subchapter 4.3, Erosion.

4.6 SPILLWAYS

Many dams have pipes (or conduits) that serve as principal spillways. These conduits are required to carry normal stream and small flood flows safely past the embankment throughout the life of the structure. Pipes through embankments are difficult to construct properly, can be extremely dangerous to the embankment if problems develop after construction, and are usually difficult to repair because of their location and size.

Maximum attention should be directed to maintaining these structures. The use of pipe whose joints are not designed to handle pressure flows, such as corrugated metal pipe, should be avoided when replacing or repairing existing pipe. The joints in a pipe can be affected by differential settlement of the embankment, bedding failure, positive and negative pressures within the pipe, and slides and seepage through the embankment. Therefore, it is imperative that pipe with pressure tight joints that can withstand minor deflections be used in a dam.

Frequent inspection is necessary to ensure the spillway conduit is functioning properly. All conduits should be inspected thoroughly once a year. Conduits which are 30 inches or more in diameter can be entered and visually inspected. The conduits should be inspected for improper alignment (sagging), separation and displacement at joints, cracks, leaks, surface wear, loss of protective coatings, corrosion, and blockage.

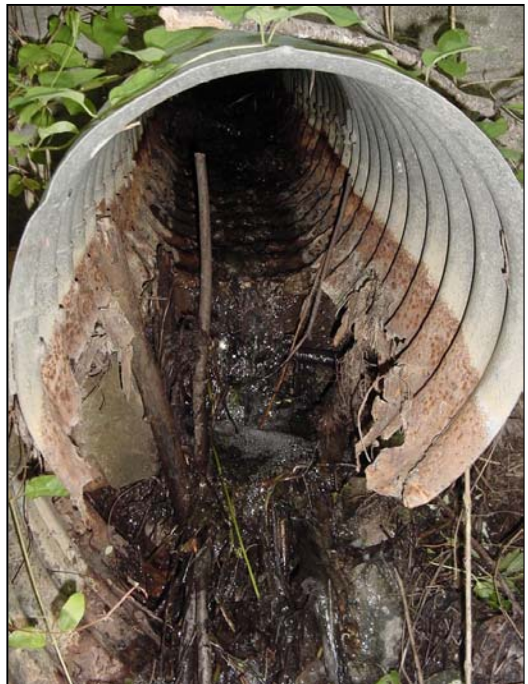

Figure 4-6 This corrugated metal pipe is completely rusted through on the bottom, creating a safety concern. Metal pipes are not recommended for use in dams.

Problems with conduits occur most often at joints, and special attention should be given them during the inspection. The joints should be checked for gaps caused by elongation or settlement and loss of joint-filler material. Open joints can permit erosion of embankment material or cause leakage of water into the embankment during pressure flow. The outlet should be checked for signs of water seeping along the exterior surface of the pipe. A depression in the soil surface over the pipe may be a sign that soil is being removed from around the pipe.

Effective repair of the internal surface or joint of a conduit is difficult and should not be attempted without careful planning and proper professional supervision. Listed below are comments regarding pipe repairs.

- Asphalt mastic used as joint filler becomes hard and brittle, is easily eroded, and will generally provide a satisfactory seal for only about five years. Mastic should not be used if the pipe is expected to flow under pressure. For these reasons asphalt mastic is not recommended for other than temporary repairs.
- The instructions on the label should be followed when using thermosetting plastics (epoxy). Most of these products must be applied to a very clean and dry surface to establish an effective bond.
- Material used as joint filler should be impervious to water and should be flexible throughout the range of expected air and water temperatures.
- The internal surfaces of the conduit should be made as smooth as possible when

repairs are made so that high-velocity flow will not damage the repair material.
- Hairline cracks in concrete are not generally considered a dangerous problem and repair is not needed unless the cracks open up or transmit water.

A common problem with pipe spillways and other conduits made of metal is corrosion. Exposure to moisture, acid conditions, or salt will accelerate the corrosion process. Acid runoff from strip-mine areas will cause rapid corrosion of metal pipes. Metal pipes are available which have been coated to resist accelerated corrosion. Coatings can be of epoxy, aluminum, or zinc (galvanized). Coatings applied to pipes in service are generally not very effective because of the difficulty in establishing a bond. Bituminous coatings cannot be expected to last more than one or two years on flow ways. Corrosion can be controlled or arrested by installing cathodic protection. A metallic anode such as magnesium is buried in the soil and is connected to the metal pipe by wire. Natural voltage causes current to flow from the magnesium (anode) to the pipe (cathode) and will cause the magnesium to corrode and not the pipe. Corrosion shortens the life of metal pipes through dams. The corrosion rate is dependant upon the soil PH, water content, metal thickness, and overburden load. All metal pipes need to be closely monitored with respect to operation of the pipe. Metal pipes are not recommended and should be upgraded to concrete when repairs are required.

Corrosion of metal parts of operating mechanisms can be effectively treated and prevented by keeping these parts oiled and/or painted.

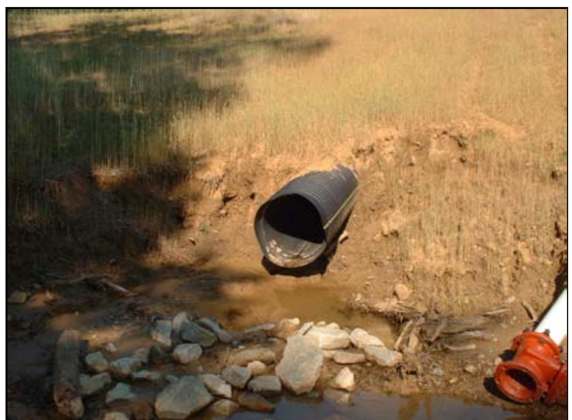
Figure 4-7 Erosion at the outlet of a principal spillway discharge pipe. Note that the pipe is plastic, which is not recommended for use as a principal spillway structure.

Erosion at the spillway outlet, whether it be a pipe or overflow spillway, is one of the most common spillway problems encountered. Severe undermining of the outlet can displace sections of pipe, cause slides in the downstream slope of the dam as erosion continues, and eventually lead to complete failure of a dam. Water must be conveyed safely from the lake to a point downstream of the dam without endangering the spillway or embankment. Often the spillway outlet is adequately protected for normal flow conditions, but not for extreme flows. It is easy to underestimate the energy and force of flowing water or overestimate the resistance of the outlet material (earth, rock, concrete, etc). The required level of protection is hard to establish by visual inspection but can usually be determined by hydraulic calculations performed by a professional engineer.

Structures that provide complete erosion control at a spillway outlet are usually expensive to construct, but often necessary. Less expensive types of protection can be effective, but require more extensive periodic maintenance. As areas of erosion and deterioration develop, repairs must be promptly initiated. To properly correct the problem, the cause of the damage must be determined. The following four factors, often interrelated, contribute to erosion at the spillway outlet.

1) Flows emerging from the outlet are normally at an elevation above the stream channel. If the outlet flows emerge at the correct elevation, tailwater in the stream channel can absorb a substantial amount of the high velocity flow.
2) Flows emerging from the spillway are generally free of sediment and therefore have substantial sediment-carrying capacity. In obtaining the appropriate sediment load, the moving water will scour soil material from the channel and leave eroded areas. Such erosion is difficult to estimate and requires that the outlet be protected for a safe distance downstream from the dam.
3) Flows leaving the outlet at high velocity can create negative pressures that can cause material to be loosened and removed from the floor and walls of the outlet channel. This action is known as "cavitation" and can affect concrete or metal surfaces. Venting can sometimes be used to relieve negative pressures; however, the size and location of a vent should be determined by a professional engineer.
4) Water leaking through pipe joints or flowing along a pipe from the reservoir may weaken the soil structure around the pipe. Inadequate compaction adjacent to the structure during construction and the absence of sand diaphragms will compound the problem.

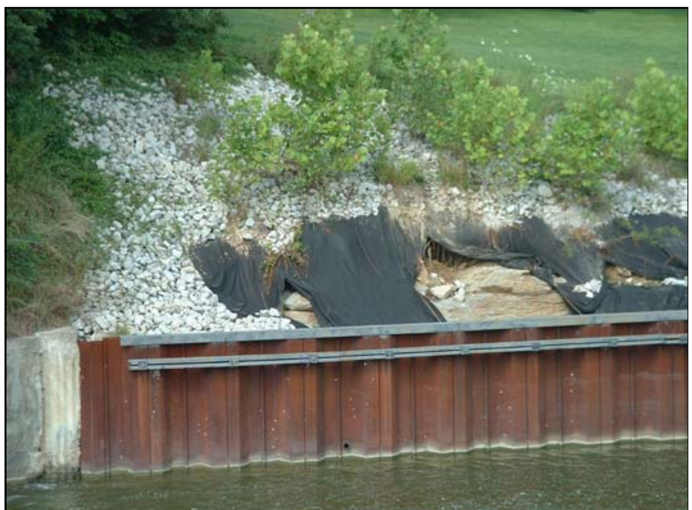

Figure 4-8 Erosion of fill behind this wall at the outlet of the principal spillway was caused by water splashing over the wall during a large storm event. Larger rock or concrete will be required to prevent this from happening again.

Eroded and undermined areas at spillway outlets can sometimes be repaired by filling these areas with large stone. Stone that is large enough to be effective needs to weigh in excess of 500 pounds (18 to 24 inches in diameter). Often stones this size are not available or are expensive to buy and haul. Owners should be aware that placing large stones in the undermined areas adjacent to spillway outlets may not solve a problem. Often these eroded areas are a result of a more serious problem with the dam. Gabions have been used successfully in areas where the velocity is low but should not be used where high velocity and turbulence are expected. Gabions require careful foundation preparation and experienced personnel for Installation. Properly designed plunge pools are acceptable but can require frequent maintenance. In many cases, professional help should be sought for complete redesign and construction of the outlet.

The function of an emergency spillway is to convey flood flows past the dam in a manner that will ensure that the dam is not overtopped. Vegetated-earth, rock, and concrete spillways are commonly used as an economical means to provide emergency spillway capacity. Normal flows are carried by the principal spillway, and infrequent, large flood flows pass primarily through the emergency spillway. For dams with pipe conduit spillways, an emergency spillway is almost always required as a back-up in case the pipe becomes plugged. These spillways are often neglected because the owner rarely, if ever, sees them flow. Emergency spillways usually are designed to flow only once every 25 to 100 years or more; however, maintenance is still very important.

Maintenance of vegetated-earth spillways is covered under earlier Subchapters 4.2 and 4.3. Additionally obstructions in the spillways should be removed immediately after their discovery.

Emergency spillways often are used for purposes other than passage of flood flows. Among these uses are reservoir access, parking lots, boat ramps, boat storage, pasture, and cropland. Permanent structures (buildings, fences, etc.) should not be constructed in emergency spillways. If fences are absolutely necessary, they should cross the spillway far enough away from the crest (control section) so they do not interfere with flow. After flows occur, the fences should be cleared of all debris, trees, and brush.

Maintenance of rock spillways should include the periodic removal of trees, brush, and debris from flood flows and rock slides. Rock slides can be a major problem in areas where open channel spillways have been cut into weathered or highly fractured rock. Large rock that has fallen into the channel can partially block an emergency spillway and reduce its discharge capacity. Rock spillways should be inspected frequently and cleaned out whenever debris accumulates in the channel. Erosion of rock spillways is not normally a problem; however, many spillways are constructed adjacent to the dam and founded partially in rock and partially in natural soil or fill material. In these cases, a training berm is required to direct flows away from the dam. This berm and the channel side next to the dam should be inspected for erosion whenever the spillway is used. Erosion protection consisting of riprap or concrete and designed to hold up under the velocities expected during the spillway design flood should be provided and maintained.

Figure 4-9 The floor and side walls of this concrete spillway are badly deteriorated and in need of repair.

Maintenance of concrete spillways should include keeping the channel clear of debris, filling joints and cracks, keeping underdrains open and maintaining the structural stability of the concrete. Concrete spillways must be inspected for cracks or displacements caused by settlement, foundation failure, uncontrolled seepage, and frost action. Voids created by the settlement of compressible soils beneath spillways and uncontrolled seepage may cause the concrete to crack or displace due to lack of support. When temperatures fall below the freezing point, water located in the soil voids begins to freeze. Ice lenses can form and cause the concrete to crack and displace by a mechanism known as "frost heave." It is important to provide adequate drainage for concrete located on soil. Drains under concrete must be kept clear. Clogged or plugged drains, and inadequate filter systems can cause saturated conditions beneath the concrete. More information on concrete rehabilitation and seepage is contained in the subchapter on Concrete Repair.

4.7 TRASH RACKS

Many dams in Indiana have pipe and riser spillways. Pipe spillway inlets that become plugged with debris or trash reduce spillway capacity. As a result, the potential for overtopping the dam is greatly increased, particularly if there is only one spillway. If the dam has an emergency spillway channel, a plugged principal spillway will cause more frequent and greater flow in the emergency spillway. Because emergency spillways are generally designed for infrequent flows of short duration, serious damage will likely result from greater flows. For these reasons, trash racks or collectors must be installed at the inlets to pipe spillways and lake drains. If no trash rack is present, one should be installed immediately.

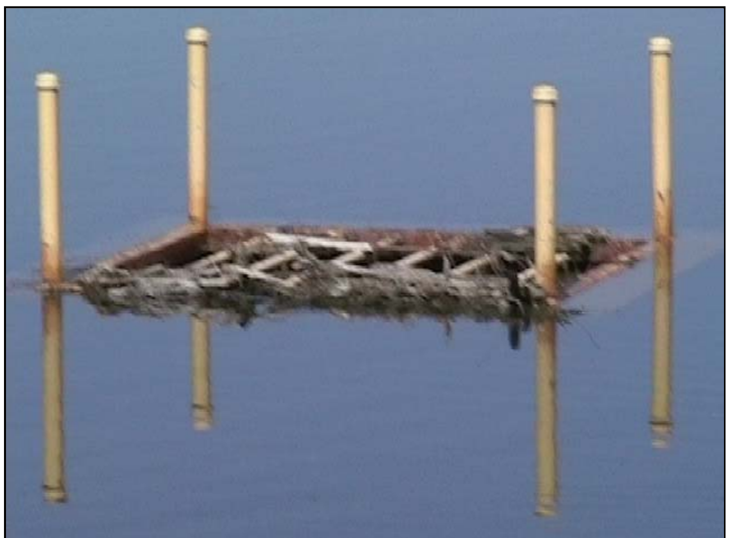

Figure 4-10 This is an example of a bad trash rack design. Trash racks should not be designed or constructed to be one-dimensional (flat, flush with water surface); this design almost guarantees clogging.

A well-designed trash rack will stop large debris that could plug the pipe but allow unrestricted passage of water and smaller debris. Some of the most effective trash racks allow flow to pass beneath the trash rack into the riser inlet as the pool level rises. Trash racks usually become plugged because the openings are too small or the head loss at the rack causes material and sediment to settle and accumulate. Small openings will stop small debris such as twigs and leaves, which in turn cause a progression of larger items to build up, eventually blocking the inlet. Trash rack openings should be at least 6 inches across regardless of the pipe size. The larger the principal spillway conduit, the larger the trash rack opening should be. The largest possible openings should be used, up to a maximum of about 12 inches.

The trash rack should be properly attached to the riser inlet and strong enough to withstand the hammering forces of debris being carried by high-velocity flow, a heavy load of debris, and ice. If the riser is readily accessible, vandals will throw riprap and debris into it. To prevent such vandalism, the size of the trash rack openings should not be decreased, but rock that is larger than the openings, too large to handle, or covered with concrete slurry should be used. Maintenance should include periodic inspections for rusted and broken sections and repairs made as needed. The trash rack should be checked frequently during and after storms to ensure it is functioning properly and to remove accumulated debris.

4.8 RIPRAP

A dam owner should expect some deterioration (weathering) and displacement of riprap. Freezing and thawing, wetting and drying, abrasive wave action, and other natural processes will eventually break down or remove the riprap. Its useful life varies with the characteristics of the stone used. Stone for riprap should be rock that is dense and well cemented. Due to the high initial cost of rock riprap, its durability should be determined by appropriate testing procedures prior to installation.

A serious erosion problem called "beaching" can develop on the upstream slope of a dam as discussed earlier. The upstream face of a dam is commonly protected against wave erosion and resultant beaching by placement on the face of a layer of rock riprap over a layer of filter material. Sometimes, materials such as steel, bituminous or concrete facing, bricks, or concrete blocks are used for this upstream slope protection. Protective beaches are sometimes actually built into small dams by placing a berm (8 to 10 feet wide) along the upstream face a short distance below the normal pool level thereby providing a surface on which wave energy can dissipate. Generally, however, rock riprap provides the most economical and effective protection.

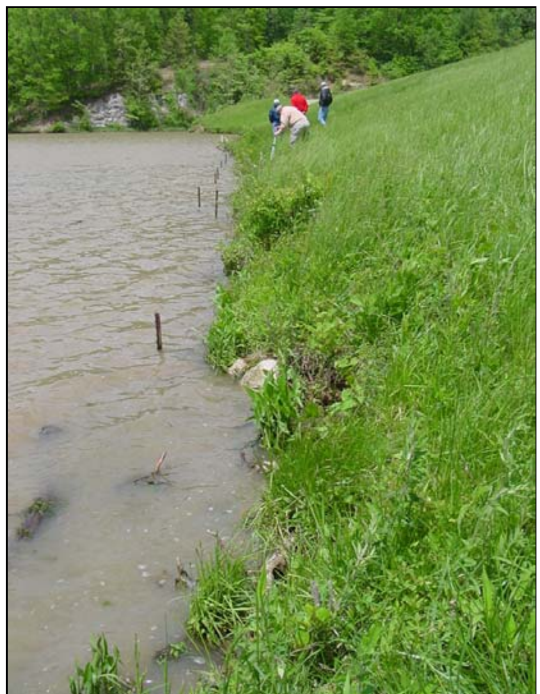

Figure 4-11 Embankment dam exhibiting minor shoreline erosion.

Nonetheless, beaching can occur in existing riprap if the embankment surface is not properly protected by a filter. Sections of riprap which have slumped downward are often signs of this kind of beaching. Similarly, concrete facing used to protect slopes may fail because waves wash soil from beneath the slabs through joints and cracks. Detection of this problem is difficult because the voids are hidden and failure may be sudden and extensive. Effective slope protection must prevent soil from being removed from the embankment.

When erosion occurs and beaching develops on the upstream slope of a dam, repairs should be made as soon as possible. The pool level should be lowered and the surface of the dam prepared for repair. A small berm or "bench" should be built across the face of the dam at the base of the new layer of protection to help hold the layer in place. The size of the bench needed depends on the thickness of the protective layer. The riprap layer should extend a minimum of 3 feet below the lowest expected normal pool level. See Subchapter 4.3 for a description of riprap placement repair.

The useful life of riprap varies depending on the characteristics of the stone used. Thus, stone for riprap should be rock that is dense and well cemented. When riprap breaks down, and erosion and beaching occur more often than once every three to five years, professional advice should be sought to design more effective slope protection.

4.9 CONCRETE REPAIR

This subchapter presents a brief overview of concrete repair methods, obtained from the U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center *Guide to Concrete Repair*, 1997; U.S. Government Printing Office, Washington, D.C. 20402-9328.

Concrete is an inexpensive, durable, strong, basic building material often used in dams for core walls, spillways, stilling basins, control towers, and slope protection. However, forces of nature and poor design, workmanship, construction procedures, and materials may cause imperfections that later require repair. Long term deterioration or damage caused by flowing water, ice, or other natural forces must be corrected.

Concrete surfaces should be examined for spalling and deterioration due to weathering, unusual or extreme stresses, alkali or other chemical action, erosion, cavitation, vandalism, and other destructive forces (see Part 3).

Structural problems are indicated by cracking, exposed reinforcing bars, large areas of broken-out concrete, misalignment at joints, undermining, and settlement. Rust stains may indicate internal rusting and deterioration of reinforcement steel. Spillway floor slabs and upstream-slope protection slabs should be checked for undermining (erosion of base materials). Concrete wall and tower structures should be examined for settlement and their alignment checked. Concrete surfaces adjacent to contraction joints and subject to flowing water are of special concern. The adjacent surfaces must be flush or the downstream edge slightly lower to prevent erosion of the concrete and to prevent water from being directed into the joint during high velocity flow. All joints should be kept free of vegetation. All weep holes should be checked for blockage, and stain outlines on concrete surfaces studied for indications of flow characteristics.

Floor or wall movement, extensive cracking, improper alignments, settlement, joint displacement, and extensive undermining are signs of major structural problems. Drainage systems may be needed to relieve excessive water pressures under floors and behind walls. Because of their complex nature, major structural repairs require professional advice and are not addressed here.

The United States Department of the Interior, Bureau of Reclamation has developed a seven-step repair system for concrete that is an excellent procedure. The Bureau of Reclamation has developed, used, and evaluated this procedure over an extended period of time, and has found it to be suitable for repairing construction defects in newly constructed concrete as well as old concrete that has been damaged by long exposure and service under field conditions. The methodology is presented in their manual, "Guide to Concrete Repair," April 1997, Technical Service Center; it is for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington D.C. 20402.

The repair system will be found most useful if followed in a numerically sequential or step-wise manner. Quite often, the first questions asked about deteriorated or damaged concrete are: "What should be used to repair this?" and "How much is this going to cost?" These are not improper questions, however, they are questions asked at an improper time. Ultimately, these questions must be answered, but pursuing answers to these questions too early in the repair process may lead to incorrect and, therefore, extremely costly solutions. If a systematic approach to repair is used, such questions will be asked when sufficient information has been developed to provide correct and economical answers.

The Bureau of Reclamation's seven step repair system is as follows:

1. Determine the cause(s) of damage
2. Evaluate the extent of damage
3. Evaluate the need to repair
4. Select the repair method
5. Prepare the old concrete for repair
6. Apply the repair method
7. Cure the repair properly

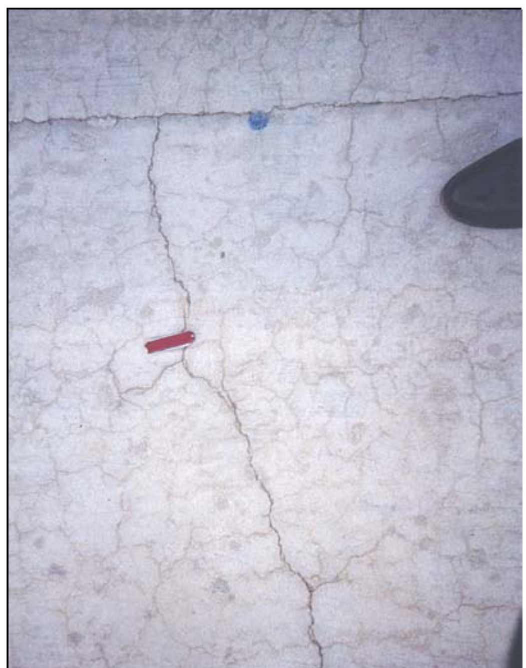

Figure 4-12 A large reflective crack has formed in a concrete overlay which also exhibits circular drying shrinkage cracking.

1. Determine the Cause(s) of Damage

The first and often most important step of repairing damaged or deteriorated concrete is to correctly determine the cause of the damage. If the cause of the original damage to concrete is not determined and eliminated, or if an incorrect determination is made, whatever damaged the original concrete will likely also damage the repaired concrete. Money and effort spent for such repairs is, thus, totally wasted. Additionally, larger and even more costly replacement repairs will then be required.